REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
FINAL REPORT 01 Aug 95 - 31 Jul 96

4. TITLE AND SUBTITLE
(DURIP-95) Optical Frequency Shifters and Phase Detectors Based on Novel Semiconductor Structures

5. FUNDING NUMBERS
61103D
3484/US

6. AUTHOR(S)
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AFOSR-TR-96
0581

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NE
110 Duncan Avenue Suite B115
Bolling AFB DC 20332-8080

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
F49620-95-1-0482

11. SUPPLEMENTARY NOTES

19961223 023

12a. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

13. ABSTRACT *(Maximum 200 words)*

After this grant was awarded and the matching fund was provided by Bowling Green State University, we purchased a YAG-laser-pumped optical parametric oscillator, which consists of three major components. We have optimized our multilayer structures for surface-emitting second-harmonic generation, transversely-pumped counter-propagating optical parametric amplification, and difference-frequency generation. We are currently characterizing this sample using our new laser system. The parametric processes will enable us to efficiently generate coherent light in the mid-infrared domain. Recently, we proposed backward optical parametric oscillators, amplifiers, and second-harmonic generation. Most recently, we observed backward second-harmonic gesneration in these crystals.

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

Final Technical Report

Optical frequency shifters and phase detectors based on novel semiconductor structures

(FY95 DURIP; Grant No. F49620-95-1-0482)

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After this grant was awarded and the matching fund was provided by Bowling Green State University, we purchased a YAG-laser-pumped optical parametric oscillator, which consists of three major components:

1. Model GCR-230-10, Nd:YAG Laser, 1250 mJ@1064 nm, 10 Hz.
2. EEO-4-355, Enhanced Energy Option for GCR-230-10.
3. MOPO-730, High Efficiency, Narrow Band ($<0.2\,cm^{-1}$), Master Oscillator/Power Oscillator OPO (includes remote).

The key to the power oscillator is the use of a geometrically unstable resonator design. Such type of the oscillator provides high energy output pulses, with excellent divergence and transverse mode control. This resonator provides an output beam with a smooth, Gaussian-like profile, minimal structure and sub milliradian divergence at all signal wavelengths. The master oscillator output provides the seed for the narrow-linewidth operation. This system manufactured by Spectra-Physics Lasers (SPL) was installed in Feb. of this year. Because we need a Gaussian-like spatial profile for the idler wave in the wavelength domain of 1.2 μm - 1.8 μm to be coupled into a planar waveguide, SPL engineer modified the pumping configuration in June and September. In the new configuration, the BBO crystal was pumped by two counter-propagating Nd:YAG laser beams.

Meanwhile we have optimized our multilayer structures for surface-emitting second-harmonic generation [1], transversely-pumped counter-propagating optical parametric amplification [2], and difference-frequency generation [3]. We have grown the first multilayer structure in collaboration with Wright Lab (Dr. Loehr's group) to investigate these nonlinear processes. The center pump, input and output wavelengths are designed to be 1.06 μm, 1.58 μm, and 3.23 μm. The structure is shown in Fig. 1. We are currently characterizing this sample using our new laser system. We will grow more samples with different structures to implement these nonlinear processes in collaboration with Naval Research Lab (Dr. Rabinovich's group).

The parametric processes mentioned above will enable us to efficiently generate coherent light in the mid-infrared domain. These processes can be used to generate new frequencies in the vicinity of input one for narrow-band optical communications [4]. There are certain advantages of frequency shifting based on our schemes. We can tremendously reduce the band-to-band absorption of all the beams. A high Q-vertical-cavity can be readily incorporated during growth to enhance the efficiency of the frequency conversion. Even without the presence of a traveling-wave amplifier, there is a gain for sufficiently high pump power. Effective interaction length is maximized. Our frequency shifters can be integrated with semiconductor lasers. Eventually, our shifters can be electrically pumped and only take one input wave. We can integrate a vertical-cavity surface-emitting laser with transversely-pumped counter-propagating difference-frequency generation for an electrically-pumped frequency shifter. In addition, optical signal can be amplified and its phase can be stablized and detected. The parametric processes can be used to perform wavelength-division multiplexing. We believe after the frequency shifters and phase detectors are implemented, they will eventually make dramatic impact on optical communications.

Recently, we proposed backward optical parametric oscillators, amplifiers, and second-harmonic generation [5]. We periodically poled $LiNbO_3$ crystals in collaboration with Naval Research Lab [6]. Most recently, we observed backward second-harmonic generation in these crystals [6], see Fig. 2. We will use our new laser system to implement these parametric devices in quasi-CW regime. We will also use this laser system to demonstrate principle operation of several new devices proposed by us recently, such as directional couplers, phase conjugation, self-phase modulation, and power limiters.

[1] Y. J. Ding, S. J. Lee, and J. B. Khurgin, J. Opt. Soc. Am. B 12, 1586 (1995).

[2] Y. J. Ding, S. J. Lee, and J. B. Khurgin, Phys. Rev. Lett. 75, 429-432 (1995); IEEE J. Quant. Electr. 31, 1648-1658 (1995).

[3] Y. J. Ding and J. B. Khurgin, submitted to J. Opt. Soc. Am. B.

[4] O. Gorbounova, Y. J. Ding, S. J. Lee, and J. B. Khurgin, and A. E. Craig, Opt. Lett. 21, 558 (1996).

[5] Y. J. Ding and J. B. Khurgin, IEEE J. Quantum Electron. 32, 1574 (1996); Opt. Lett. 21, 1445 (1996).

[6] J. U. Kang, W. K. Burns, Y. J. Ding, and J. S. Melinger, submitted to CLEO'97.

(a)

(b)

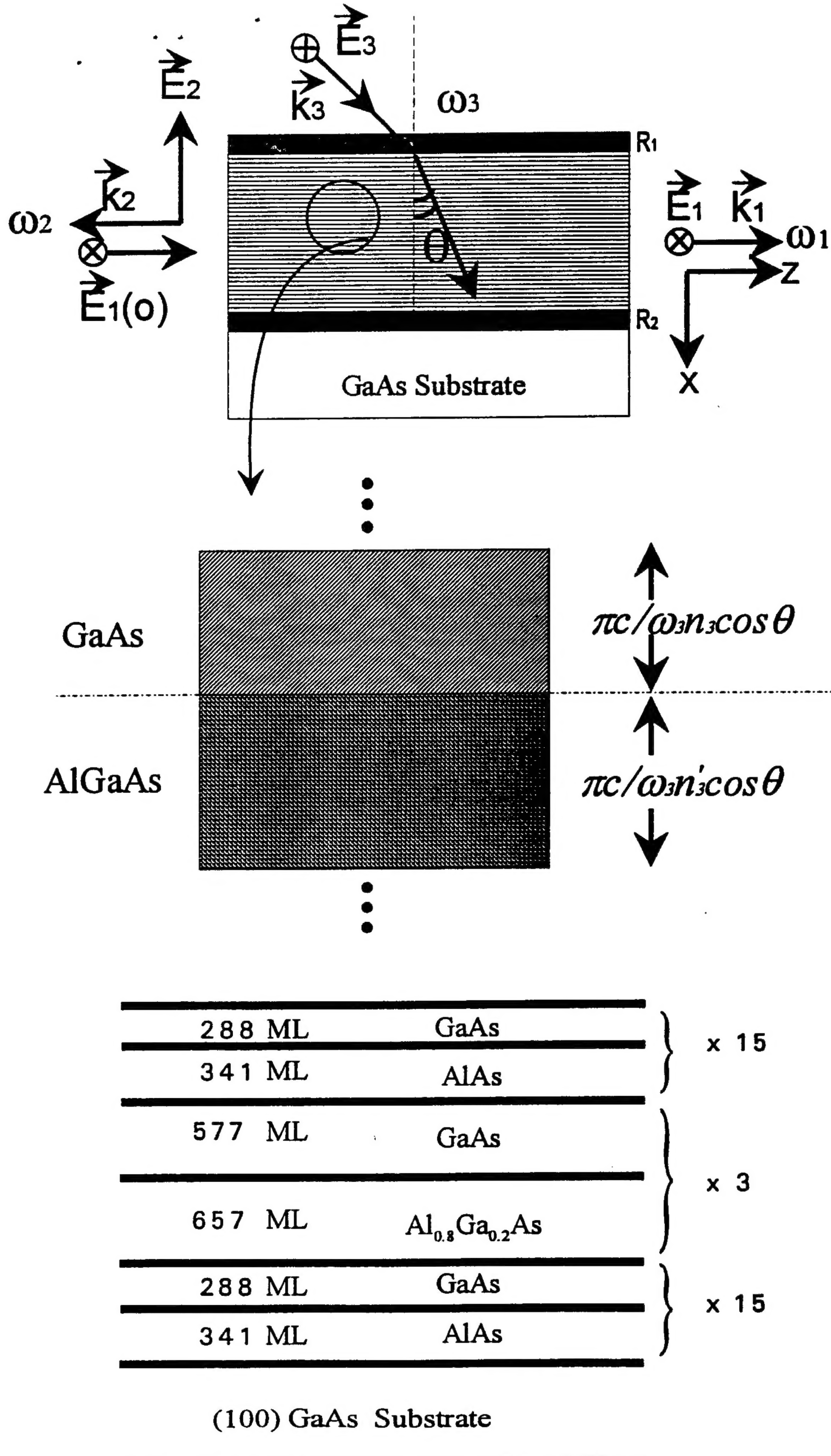
E3
E2
k3
ω3
R1
k2
ω2
E1
k1
ω1
Z
E1(o)
θ
R2
GaAs Substrate
X
GaAs
AlGaAs
πc/ω3n3cosθ
πc/ω3n'3cosθ
288 ML GaAs
341 ML AlAs
x 15
577 ML GaAs
657 ML Al0.8Ga0.2As
x 3
288 ML GaAs
341 ML AlAs
x 15
(100) GaAs Substrate

Fig. 1

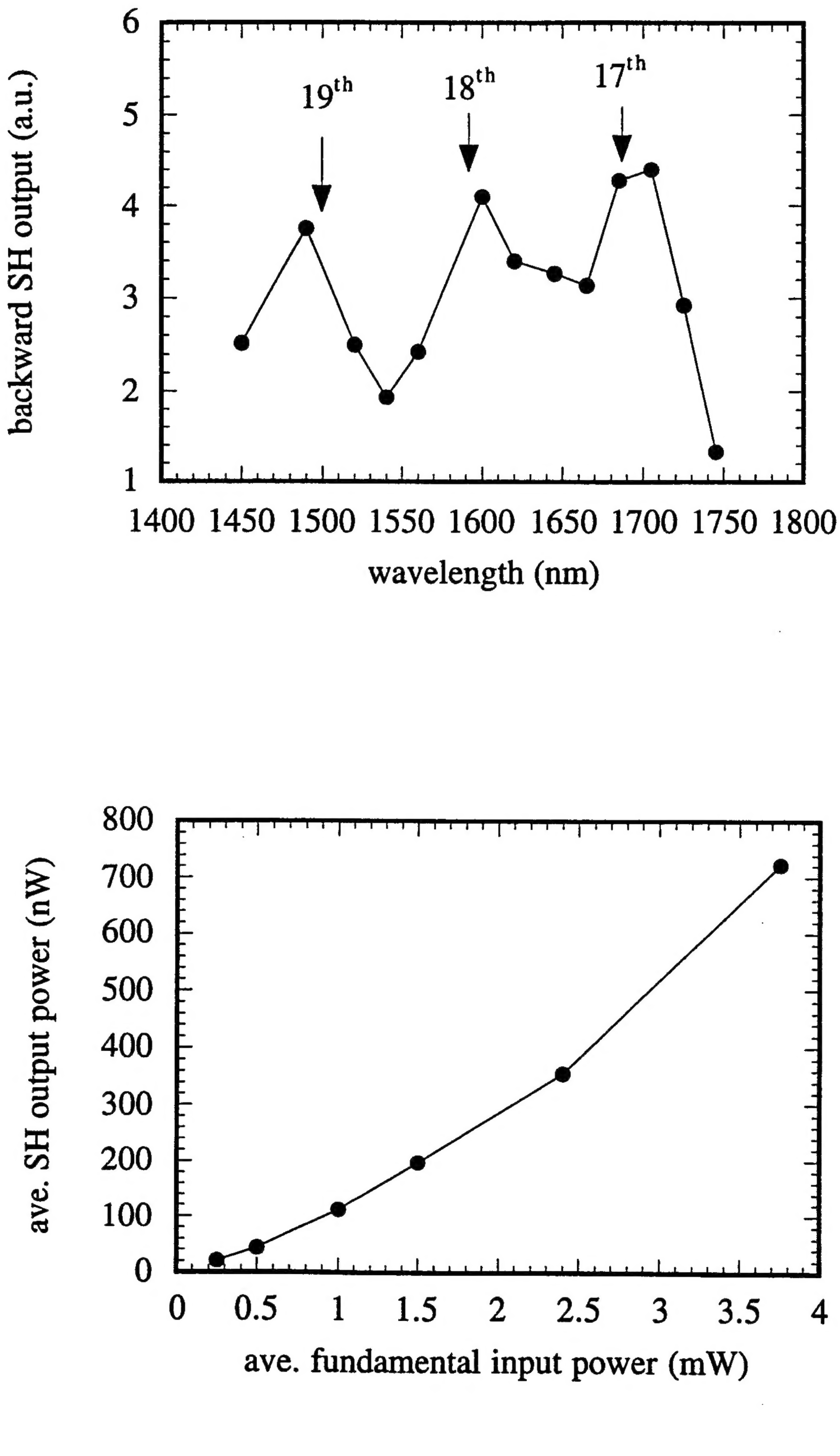
6
5
4
3
2
1
19th
18th
17th
backward SH output (a.u.)
1400 1450 1500 1550 1600 1650 1700 1750 1800
wavelength (nm)
800
700
600
500
400
300
200
100
0
ave. SH output power (nW)
0 0.5 1 1.5 2 2.5 3 3.5 4
ave. fundamental input power (mW)

Fig. 2